C-5 CHANNEL DELAYS: ANALYSIS OF POTENTIAL CAUSAL FACTORS

GRADUATE RESEARCH PAPER

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Abstract

The Air Mobility Command channel system is an essential part of the Department of Defense supply chain network. While the C-5 Galaxy is a key contributor to channel mission success, delays have plagued operations and reduced the effectiveness and efficiency of deliveries to the warfighter. Inappropriate manning levels and performance measurement techniques have hampered maintenance efforts at home-station and enroute locations. Additionally, current mission management practices increase the perception of unreliability in the C-5. However, even when considering only new and unique situations, the Galaxy has an inordinate number of crew and maintenance delays that are characterized by an excessive severity.

This research attempted to establish a correlation between the propagation and severity of C-5 mission delays in the channel system and five distinct (but not independent) variables. The variables considered were aircraft type, aircraft home station, aircrew service component, departure location, and combat status. The researcher was unable to demonstrate a correlation with any level of significance. However, the results set a baseline for comparison between mission variables and provide inputs to a tool that can be used to predict the severity of delays that may occur.

The researcher developed an Excel-based instrument that uses historical data to predict delay severity based on given values for only those variables considered in this study. A user-friendly input section is provided and outputs are presented both numerically and graphically. While this instrument should not be used as the sole source for C-5 delay decision making, it provides a starting point for the decision process.

To my amazing wife and children

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I would like to thank my sponsor, Mr. Don Anderson from the Air Mobility Command Analysis, Assessments and Lessons Learned Directorate, for agreeing to sponsor this study, providing data and existing research, and giving direction throughout the year. His expertise and insight was crucial to the completion of this project.

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Finally, I would like to thank Expeditionary Center Librarian Pamela Bennett Bardot, who combed through countless journals searching for studies related to the focus of this project. Her dedication to research, to the point of searching for English translations of a Serbian journal, was exemplary.

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I. Introduction

Background

United States Transportation Command (TRANSCOM) exists for one purpose only…the timely and dependable movement of people and cargo. The current TRANSCOM vision emphasizes General Duncan McNabb's goal of synchronizing and delivering "unrivaled, full-spectrum deployment and distribution solutions" (TRANSCOM, 2010). Unfortunately, shortfalls in delivery speed and reliability have built up an understandable lack of trust from users. As one study found, those relying on TRANSCOM can incur "costs associated with an unpredictable transportation system, such as increased ordering costs because of duplicate orders, increased inventory, and increased inventory holding costs" (Condon and Patterson, 2004: 33). The velocity and reliability of the military air transportation system are the clearest indicators of TRANSCOM's success…or its failure.

Air Force Doctrine Document 2-6 identifies specific common user Transportation Working Capital Fund (TWCF) mission categories: channel, special assignment airlift missions (SAAM), exercise and contingency. It also states that under normal conditions, "movement requirements are fulfilled through regularly scheduled missions over fixed route structures with personnel/cargo capacity available to all common users" (AFDD, 2006: 35). These regularly scheduled 'channel' missions are the backbone of TRANSCOM's air transportation network. The C-5 Galaxy, despite its reputation for unreliability, is a heavily-used asset in the channel system.

The first C-5 Galaxy entered service as part of the Air Force inventory in June, 1970 (AF Fact Sheet, 2009). Unfortunately, aircraft reliability has been a serious concern for military leadership since they were added to the mobility inventory. Air Force leaders rely on Departure Reliability (DR) and Mission Capability (MC) rates to measure C-5 performance, and DR for C-5 channel missions is far below the desired level. DR can be affected by weather, diplomatic clearances, or other factors, but there is a perception that equipment failures drive most mission delays. In reality, mission data has shown that while maintenance is a major contributor, it may not be the primary reason for delays. In the first quarter of 2010, 81% of C-5 channel departures operated in some sort of delay, but only 31% of those delays were due to maintenance (Anderson, 2010). MC rates measure the percentage of aircraft functioning at levels that allow mission completion. Low MC rates are common, with 2005-2007 data showing C-5 MC "rates of only 48% for C-5A/C and 65% for C-5B" (Knight and Bolkcom, 2008: 4). Potential causal factors for the C-5's unacceptable performance have never been thoroughly investigated or defined beyond a broad 'poor maintenance' label. More importantly, Air Mobility Command (AMC) leadership has grown so accustomed to maintenance delays on C-5 channel missions that they are an expected occurrence.

Motivation and Implications

Poor post-delay mission management has the potential to negatively impact the warfighter due to delayed deliveries. Ongoing troop and cargo movements in support of multiple combat efforts should stress the value of minimizing delays. However, lowered priority and relaxed required delivery date (RDD) on channel mission cargo have reduced the perceived importance of addressing the issues facing channel mission planners.

Numerous factors may be causal when considering channel delays, but mission planners and leadership have operated under the false assumption that all missions will go as scheduled. Even worse is the belief that channel missions will probably have significant delays, but that it does not matter. Presentation of a complete picture of all factors influencing delay statistics and a demonstration of the system-wide impact of those delays could be extremely beneficial for AMC leadership. Also, providing a time-based decision point for personnel at the 618th Tanker Airlift Control Center Global Channel Operations Directorate (TACC/XOG) could assist channel mission managers when considering the cancellation of delayed C-5 channel missions.

Results of this study could have significant impact on the processes used during the planning and execution of C-5 channel missions. Specifically, decision makers could gain a greater capability to make informed decisions when considering delayed missions. Also, this information could be crucial to AMC efforts highlighting the significance of channel delays and factors that influence them. Finally, this study could be used to pursue further research in the modeling of delays and the development of best practices to minimize delay propagation and severity during mission execution.

Problem Statement

AMC leaders and mission planners do not have a complete picture of the factors that may contribute to channel mission delays. Specifically, it is necessary to determine potential causal factors (beyond those already reported) and the relative impact of those factors for C-5 channel mission delays. Additionally, TACC/XOG leadership has identified the need for a time-based decision point beyond which increasing consideration should be given to cancelling a delayed C-5 channel mission.

Research Objective and Research Questions

The primary goal of this research is to explore and demonstrate the relative impact of each (or a combination) of certain factors on the possibility and severity of C-5 channel delays. Once identified, this research develops a tool that could demonstrate the effects of these factors during planning and/or execution.

An unfortunate but popular perception among Air Force personnel is that C-5 crews choose to 'break' when they are in desirable locations. Another widely-held belief is that missions on older aircraft or those flown by Guard and Reserve crews will have higher delays. This research answers the following questions:

1. Over a specified data period, what was the C-5 channel mission delay propagation and severity with respect to aircraft model, aircraft home station, aircrew service component, departure location and combat status?
2. Given the results of the above question, can a tool be developed to demonstrate the impact of these variables on channel delays and develop time-based cancellation decision points for TACC planning and execution cells?

Research Focus

This research is a quantitative study of mission specific information for C-5 channel missions over a one-year period. Specifically, aircraft model (C-5A/B/M), aircraft home station, air crew service component (Active Duty/Guard/Reserve), combat status, and delay location are considered. All data was provided by AMC's Analysis, Assessments and Lessons Learned Directorate (AMC/A9), which queried GDSS2 databases to provide mission-specific information on all C-5 channel missions over the specified one-year period.

Statistical data analysis for this study is primarily limited to the GDSS2 mission information provided by AMC/A9. Descriptive statistics are used to determine average and expected delays based on each variable. The use of further statistical techniques, such as regression, is unreasonable given the large number of potential variables. However, descriptive data is used to develop a tool that could present the severity distribution for delays. Although there are many factors that may influence a delay, results are dependent only on the variables identified in this study.

Assumptions and Limitations

This research is limited to an analysis of the GDSS2 data provided by AMC/A9. It is assumed that all data is accurate and complete unless required information is absent. Missions missing required information are not considered as part of the study. Skewing of the data may occur, but no alternative information sources are available. Additionally, the analysis of delay severity is limited to those locations where 10 or more delays occurred to ensure the validity and significance of the results.

The planned data range for this research is 1 August 2009 to 31 July 2010. While this time period was selected to allow for mobility system changes based on seasonality, significant events during this period may also skew the data. The earthquake in Haiti and the Iceland volcano are examples of these events. The data set was retained to account for the significant possibility of similar events during other one-year periods.

The results of this research are based on an analysis of a limited data set, and results can only be applied to C-5 channel delays. Application of this research to training, contingency or Special Assignment Airlift Missions (SAAMs), or other weapons systems, could yield drastically different results.

The results of any simulation model or other tool developed should not be generalized for use when considering variables other than those used during this research. Additionally, modification of the inputs to this tool with a smaller volume of data may not provide accurate or useful information.

Finally, the development of a time-based cancellation decision point as a planning tool is based on historical data with a limited number of variables. Due to the limited nature of this standard, a decision point could be irrelevant for specific cargo loads or missions. Serious consideration should be given to other mission-specific factors such as maintenance availability, crew scheduled return time (SRT), diplomatic clearances, alternate aircraft availability, cost optimization and cargo prioritization.

Overview

The remainder of this paper attempts to address the reliability of the C-5, identify the impact of specified variables on the possibility and severity of channel delays, and provide a planning and execution tool to address delays that occur. The literature review in Chapter II summarizes C-5 development and modernization efforts, analyzes the challenges in upholding satisfactory maintenance levels with respect to metrics, and outlines mission management procedures that define aircraft reliability. Chapter III discusses the methodology used in this research for analysis of the data set with respect to the selected variables and describes the development of the tool that calculates expected delay severity. Chapter IV provides the results of the analysis broken down by each variable and discusses the outputs and viability of the tool. Chapter V presents recommendations and conclusions based on this study and suggests areas for future research related to mission and aircraft reliability.

II. Literature Review

This chapter first examines the history and development of the C-5 Galaxy weapons system. It also summarizes the findings of several studies specifically related to the operation and maintenance of the C-5. Next, it presents a brief review of current AMC-mandated mission reliability reporting procedures. Finally, existing research related to this study or similar topics is discussed.

Birth and Development of the C-5 Galaxy

The Lockheed C-5A was developed out of a perceived need for a large-capacity strategic airlifter. Specifically, military leaders in the early 1960s identified the need for rapid-response large-scale airlift to austere locations. According to *The C-5A Scandal*, the Galaxy was designed to provide a new level of flexibility. "Just 12 of them could have handled the entire Berlin Airlift, which required 224 planes in 1948" (Rice, 1971: 3). This statement, of course, relies on the assumption that those 12 C-5s could operate as scheduled.

Unfortunately, the C-5A quickly demonstrated a tendency to suffer from maintenance problems. Pressurization and hydraulic system malfunctions were commonplace, and the complexity of the caster-capable landing gear led to serious concerns for Air Force leaders. As previously referenced, the first operational C-5A was delivered in June, 1970. On touchdown at Charleston AFB, "one tire blew out upon the impact and another wheel departed from the landing gear completely, bouncing down the runway by itself, to the delight of the TV cameramen covering the event" (Rice, 1971: 161). Additionally, the C-5A struggled with wing design flaws that shortened the projected life of the aircraft from 30,000 hours to approximately 8,000 hours (Reed, 2000: 40). A 1980s wing replacement program extended the lifetime of the C-5A (and improved capability). However, maintenance issues that continued to plague the C-5 contributed to a perceived inability to effectively complete the mission.

Despite this perception, the C-5A was a major contributor to the success of a wide array of operations throughout the 1970s. A continuing growth in the need for rapid delivery of outsized cargo to austere locations led to the design of the McDonald Douglas C-17. Lockheed, in an attempt to continue the production line, proposed the production of new C-5s as "interim airlifters, pending the arrival of the C-17" (Reed, 2000: 46). These C-5Ns, later designated by the Air Force as C-5Bs, were outfitted with improved engines, brakes and avionics in addition to other modifications. Unfortunately, both models of the Galaxy continued to suffer from unacceptable mission capability rates throughout the 1990s. This poor reliability is the target of ongoing efforts to modernize the C-5 fleet.

C-5 Modernization

Despite the unique and significant capabilities of the C-5 Galaxy, it has been plagued with reliability issues. In an attempt to improve its performance, "the Air Force proposed two major modification programs designed to bring C-5 mission capable rates to a goal of 75 percent – the Avionics Modernization Program (AMP) and the Reliability Enhancement Re-engining Program (RERP)." AMP does not specifically address improvements in maintenance capability, but it ensures C-5s comply with avionics and air traffic management requirements. This improved capability prevents restrictions for missions that enter international airspace where advanced equipment could be mandated.

RERP is a major upgrade to C-5 systems with the specific goal of improving "availability, reliability, and maintainability" (Knight and Bolkcom, 2008: 4-5).

Unfortunately, C-5 modernization efforts have suffered from inconsistent leadership priorities, longer than expected timelines and rising costs. Strategic airlift requirements for the Department of Defense are outlined in the Mobility Capability Study and Quadrennial Defense Review**.** In 2006, both of these AF leadership-approved documents "called for fully modernizing the entire C-5 fleet" (Knight and Bolkcom, 2008: 15). Additionally, Gen Schwartz told members of Congress in November 2007 that the Air Force needed 111 fully modernized C-5s (Butler: 2010). However, budgetary constraints soon became problematic for RERP. The DoD decision to modernize the C-5 fleet was partly driven by the results of a 2000 Institute for Defense Analyses Study. This study calculated a (2007 adjusted) total cost for RERP of $6.96 billion, significantly less than the $17.5 billion cost identified by a December 2006 Selective Acquisition Report. When testifying on this cost growth before a Senate subcommittee, the Assistant Secretary of the Air Force for Acquisition stated that AMP upgrades were taking longer than expected and delaying RERP due to "unexpected repairs…during the modification process" (Knight and Bolkcom, 2008: 6, 17-18). Additionally, Congressional pressure to procure new C-17s has forced military leadership to consider retiring some of the C-5 fleet. Table 1 below shows the costs (in 2008) of modernizing the C-5 fleet as compared to purchasing additional C-17s.

Table 1. C-5 Modernization vs. C-17 Procurement

	Modernize C-5 Fleet	Buy More C-17s
Average Procurement Unit Cost[a]	$146.7 Million[b]	$280 Million
Estimated Flying Hour Cost[c]	$23,075[d]	$11,330
Production Rate	~12 aircraft/ year	~15 aircraft/year
Aircraft Flying Hours Remaining	26,000 hours	30,000 hours

(Knight and Bolkcom, 2008: 17)

In 2008, the DoD reduced the number of planned RERP aircraft, and current plans for the C-5 fleet include 52 C-5Ms (new designation for aircraft with AMP and RERP modifications). Gen Lichte, then the AMC commander, stated that "it makes sense to not RERP the A-models from a stewardship perspective, since the A-models are the oldest, least reliable and most costly to maintain" (Drinnon, 2010). Echoing that sentiment, Secretary of the Air Force, Michael Wynne, and General Moseley, testified that there are "bad actors" in the C-5A fleet. However, Gen Schwartz stated that he was "unaware of specific 'bad actor' C-5 aircraft." Also, during the 3-year period of 2005 to 2007, the C-5A fleet "averaged a marginally higher mission departure reliability rate (83.1%) than the C-5B fleet (81.3%). This data may lead one to conclude that C-5A mission capable rates lag behind those of the C-5B because of management decisions rather than aging aircraft maintenance issues" (Knight and Bolkcom, 2008: 8-9). The seeming disconnect between C-5 maintenance capability, departure reliability and perceptions about these performance measures led to an Air Force Logistics Management Agency (AFLMA) analysis of C-5 maintenance performance.

C-5 TNMCM Study II

Aircraft maintainers and operators define success through their ability to measure up to specified standards. One of the metrics maintainers used to determine their performance is the total not mission capable maintenance (TNMCM) rate (Howe and others, 2008: 16). TNMCM is "the average percentage of possessed aircraft that are unable to meet primary assigned missions" due to malfunctions or maintenance inspection requirements (Pendley and others, 2008: 31). TNMCM has been described as "perhaps the most common and useful metric for determining if maintenance is being performed quickly and accurately" (Pendley, 2008: 9). The AFLMA *C-5 TNMCM Study II* examined actions that could improve TNMCM rates for the C-5 fleet. From the 184 factors considered, two root factors were identified: "aligning maintenance capacity with demand, and the logistics departure reliability versus TNMCM paradigm" (Howe and others, 2008: 16).

Net Effective Personnel

Squadrons, groups and wings are designed and staffed using Unit Manning Documents (UMDs). A UMD identifies the size and composition of each unit…the authorized manning for each organization. Theoretically, each UMD provides the appropriate number of personnel and the proficiency level needed to accomplish the mission. Manpower reductions, especially among higher-time maintainers, have significantly reduced the experience level of most maintenance organizations. TNMCM rates are directly tied to the "speed of technicians executing the repair, which includes diagnosis, corrective action, and testing" (Howe and others, 2008: 19). The connection between unit capability and TNMCM rates clearly demonstrates the need for a more robust and experienced maintenance force.

The *C-5 TNMCM Study II* discussed the concept of Net Effective Personnel (NEP). Instead of only considering the number of assigned workers versus the number authorized, NEP addresses other factors that may significantly affect the workforce. Three specific factors are identified: skill-level productivity, ancillary training and availability. Skill-level productivity is a measure of worker's experience, as opposed to just their presence. It attempts to quantify the effectiveness of work, not just the quantity of time spent completing it. Air Force established skill levels (3, 5 and 7) make identification of each individual's skill an easily repeatable task. One weakness of the study is that the methodology used to determine productivity biases for each skill level is not identified. However, the logic for these assumptions is sound, and an analysis of one large maintenance squadron showed more than a 5 percent reduction of the productive workforce (Howe and others, 2008: 20).

Ancillary and computer-based training (CBT) are required for all Air Force personnel. Also, leave, official travel, and other factors may draw workers away from their primary duties. Manning documents, however, are not designed with consideration for these requirements. After applying corrections for additional training and availability, NEP calculations were completed for a generic and actual (large) maintenance organization. Results showed that "nonavailability had the biggest impact, productivity factors were next…CBT and ancillary training had the smallest impact." Descriptive statistics for the actual maintenance organization showed that even on the best days, the average NEP value represented just 30 percent of the total personnel assigned (Howe and others, 2008: 24-25). While leadership sometimes trivializes this shortage of highly-qualified personnel, this study clearly shows a shortfall in manpower and experience in Air Force maintenance organizations. Poor maintainability of the C-5 fleet is a direct result of this failure to align maintenance capability with the demands of the weapons system.

Departure Reliability versus Mission Capability

Another issue impacting C-5 maintainability is a growing disconnect between standards, capability and leadership expectations. Mission capability (MC) rate is a commonly used metric for determining the performance of the fleet. TNMCM and NMCS (not mission capable for supply) percentages are those metrics that reduce the MC rate. Many leaders see mission capability as the most important metric describing the fleet. In 1995, the General Accounting Office used unacceptable MC rates as the primary justification for C-5 modernization initiatives (GAO, 1995). However, MC requirements for the C-5 may not fall in line with its capability.

Air Force MC standards are normally developed using one (or more) of three requirements: flying hour or schedule, a contract logistics support contract, or other studies based on capability, readiness, or operational requirements. The C-5 MC standard, however, "is not based on any formal calculation or analysis…[it] was deemed a *prudent objective* for planning purposes." MC rates during war efforts are normally higher than in peacetime, but the fleet rate during Operations Desert Shield and Desert Storm was less than 71 percent and the FY03 rate during Operation Iraqi Freedom was under 64 percent (Pendley, 2008: 13). This inability to meet a standard that was developed outside the normal processes has raised concerns over the usefulness of tracking MC rates.

The *C-5 TNMCM Study II* identified a second root cause for increasing TNMCM rates for the C-5 fleet: a disconnect between the primary metrics used by local maintenance group commanders and those used by higher headquarters leadership. Specifically, Maintenance Group (MXG) commanders and other wing leaders identified home-station departure reliability (DR) as the primary metric that drove their actions, while AMC logistics leaders specified that aircraft availability (includes MC and TNMCM) was their primary metric. Based on historical data, DR is not directly aligned with MC…if DR improves, increased aircraft availability is not necessarily guaranteed (Pendley and others, 2008: 30, 32-33). Table 2 more clearly shows the disparate priorities at the various levels of maintenance responsibility.

The misalignment of priorities identified by this study has driven MXG practices that do not directly contribute to the performance metrics tracked by senior leadership. When maintenance inspections or repairs due to malfunctions are required, maintenance personnel must determine the work plan. The primary techniques used are least maintenance (work on the aircraft that can be repaired fastest), most maintenance (repair the aircraft requiring the most work), first in first out, and last in first out. Current MXG practices favor least maintenance, where the first aircraft worked are those with the lowest time requirement to return to MC status. While this helps local maintainers achieve a high DR, the MC results are "mediocre…when compared to the other policies" (Pendley and others, 2008: 35-36). These practices, in combination with inadequate manning and other factors, contribute to an overall state of unreliability and poor maintainability. Unfortunately, negative effects are not confined to the aircraft home station. Many maintenance repairs are limited to just what is necessary to allow for an on-time home station departure, and repeat discrepancies often occur at follow-on locations.

Table 2. Accountability and Attention for C-5 Aircraft Maintenance

	AMC/A4	MXG/CC	Technicians
Enterprise Goals – increase aircraft availability, reduce costs	High*	Medium	Low
Strategic Performance – deliver cargo and passengers accurately and on-time	High*	High	Medium
Operating Objectives – provide ready airplanes for the flying schedule	Medium	High*	Medium
Process Performance – isochronal inspections, unscheduled repair process	Medium	High*	High
Activity Performance – inspect and repair airplanes	Low	High	High*
* = primary accountability			

(Pendley and others, 2008: 32)

Mission Management

While maintenance procedures and metrics are critical to the success of the C-5, this study is primarily focused on the analysis of channel mission schedule deviations. AMC Instruction 10-206, Volume 6, states that deviations must be identified "when a military aircraft departs (launches) 15 minutes or more after the scheduled departure or Deviation Start Time (DST)." DST is calculated by adding the normally scheduled ground time to the time the aircraft actually arrived (blocked-in). More than 110 deviation codes are used to identify the primary reason for a mission delay, and a prefix of 'X' or 'L' defines the type of deviation. An 'X' prefix is used any time that actual departure time exceeds DST by 15 minutes or more. An 'L' prefix is used when a mission's actual departure time does not exceed the DST, but still departs "15 minutes or more after its scheduled departure time" (AMC, 2004: 27).

Departure reliability is a measure of "total 'on-time' departure rates by location regardless of cause" (AMC, 2004: 9). DR provides trend analysis information for AMC staff and "helps identify potential failure points in the mission generation process." The formula for DR is shown below in Figure 1. Unfortunately, 'L' delays are included when considering aircraft departure reliability. The inclusion of these schedule deviations results in inaccurate reporting…a delay at one location could impact the DR for every stop for the remainder of the mission. There should be some consideration given to the fact that follow-on delays could be more severe. One study has noted that "a flight delay could have a snowball effect along all down-line flights in the aircraft route and consequently along the schedule of other resources" (Abdelghany and others, 2004: 392). However, the design of the prefix system accounts for this possibility. Any departure that is delayed beyond its normally scheduled ground time (the takeoff time is 15 minutes or more past the DST) would receive an 'X' prefix.

$$\boxed{\text{DR} = (\text{ON TIME DEPARTURES} \div \text{TOTAL DEPARTURES}) \text{ X } 100}$$

Figure 1. Departure Reliability Formula (AMC, 2004: 9)

Another potential flaw in the reporting system is a limited capability in the ease of data analysis. Currently, a mission controller can input a primary and alternate cause for each schedule deviation. Remarks may also be added, but are not normally considered as a primary source of delay information. Additionally, the formula for DR is primarily used for reporting on the performance of a particular location. However, DR and MC rates have been used recently to identify shortfalls for the C-5A/B and potential success of the C-5M.   This study includes a more detailed analysis of the impact of location, aircraft type, and other variables.

Relevant Statistical Concepts

Calculation of the descriptive statistics for any data set produces specific results. The Mean, or average, of the data is also known as the Expected Value when repeated samplings are completed. The Median is “the middle” measurement in a data set, or “the point that divides a distribution into two equal halves” (Vogt, 1999: 102, 173). The Mode is the most common result in any data set.

The distribution of a sample or data set can be used to “draw conclusions about a target population from a single sample” (Brightman, 1999: 116). The most commonly observed distribution, known as the normal distribution, resembles a bell curve. It is “perfectly symmetric about its mean” (McClave et al, 2011: 206). For normal distributions, the mean and median are equal. Any time the median is different from the mean, the distribution is said to be skewed. For example, the Chi-Square (χ^2) distribution is skewed to the right and the level of skewness changes based on the degrees of freedom (sample size minus 1).

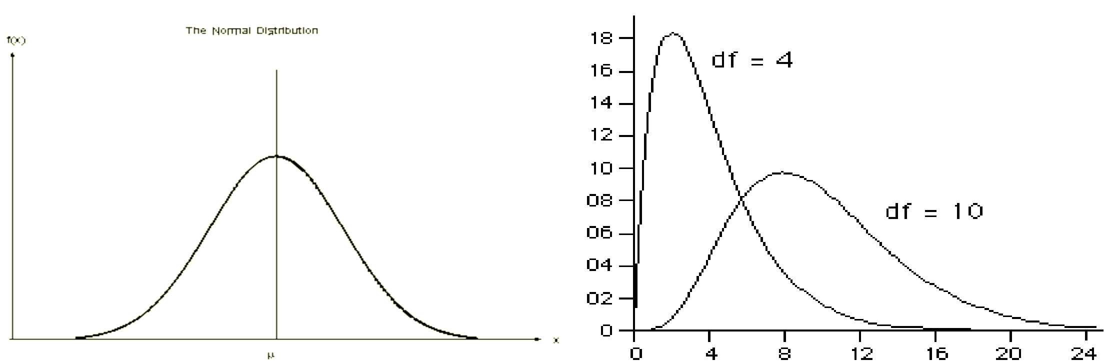


Figure 2: Normal vs. Chi-Square Distribution (Tutornext & HyperStat Online, 2011)

Existing Research

There are many studies related to the mapping, prediction and prevention of delays in the airline system. Abdelghany developed a model that projects flight delays and provides alerts for future schedule breaks during irregular airport operations (Abdelghany and others, 2004: 385). He also generated a model that could examine resource swapping and other techniques to recover an airline schedule and minimize delays (Abdelghany and others, 2008: 825). Yan utilized a “two-stage stochastic programming concept to develop a stochastic-demand flight scheduling model” (Yan and others, 2008: 24). Rupp attempted a detailed investigation of the causes of flight delays from both the airline and passenger perspectives (2007: 1). Adeleye and Chung analyzed the sequencing of maintenance and logistical turnaround activities during contingencies to develop a “framework to aid in more effective tactical decision making” (2006: 140). Many other studies could be referenced, but to the best of the author’s knowledge, only Paskota and Babic directly considered the relationship between the possibility and severity of delays and specific factors beyond the reported cause of delay. Their study used a correspondence analysis to examine flight schedule perturbations and found that the relationship between departure delay length and other factors “should be observed during the flight schedule designing process” (2006: 22).

III. Methodology

The primary goal of this research was to explore the impact of certain variables on the possibility and severity of delays during C-5 channel missions. Specifically, the researcher felt that while aircraft home station, aircraft type, combat status, and location would directly influence delays, aircrew type would have little to no impact. To address the main goal of the research, two specific sub-questions were considered. A discussion of these questions and the methodology used to examine them follows.

Data Set

This study only examined GDSS2 mission information for the specified 1-year period, 1 August 2009 to 31 July 2010, and all data was provided by AMC/A9. Data was provided in Microsoft Excel spreadsheet format and was manipulated as necessary to allow for efficient analysis. Of the 2171 lines of data provided, 165 lines were not used due to the absence of critical information. 127 of these data inputs included new delays, and would have been considered in the calculation of severity statistics. However, with less than 8% of the data removed, this data set can be considered sufficient for use in this study.

Question 1

Over a specified data period, what was the delay propagation and severity with respect to aircraft model, aircraft home station, aircrew service component, departure location and combat status?

Historical data for the specified period was mainly evaluated quantitatively through the use of the comparative method. First, a general analysis of the frequency of delays by specific delay type (code) demonstrated the propagation of delays over the data period with respect to defined categories. Following that, the Excel pivot table function was used to display number of departures, number of new delays attributed to crew or maintenance, and severity of those delays for each variable. Analysis of all other delays (attributed to weather, transportation, supply, etc.) with respect to location was completed separately. The results of the pivot tables were then manipulated to determine and/or demonstrate the following:

Table 3. Data Analysis Results

Possibility Results	Severity Results
Percent of Total Channel Departures	Percent of Total Delay Time
Percent of Total New Delays	Total Delay Time
New Delay Probability	Average Delay Severity

Additionally, descriptive statistics for the delay severity of crew/maintenance delays with respect to each variable and delay severity of other delays with respect to location provided a more succinct presentation of data distribution. More importantly, the expected value (median) for the severity tied to each variable value provided a starting point for considering the next research question.

The decision to use the median, as opposed to the mean, to determine expected severity associated with each variable seems contrary to the basic definition of these terms. The mean of a sample, by definition, is normally the expected value for the respective population. However, there are situations where "the median may be a better measure of central tendency than the mean. In particular, the median is less sensitive than the mean to extremely large or small measurements" (McClave et al, 2011: 57). Outliers are those data points that have "extreme values…[and] can distort the interpretation of data or make misleading a statistic that summarizes values (such as a mean)" (Vogt, 1999: 202). The C-5 channel mission data set is characterized by delay severities less than 25 hours, but over 15% of the delays have a severity greater than 100 hours. These outliers, with delay severities as high as 550 hours, skew the delay severity distribution. Therefore, the median provides "a more accurate picture of the typical" severity while the "mean could exceed the vast majority of the sample measurements, making it a misleading measure of central tendency" (McClave et al, 2011: 57). For the purposes of this study, the terms 'median' and 'expected' are used interchangeably.

Question 2

Given the results of the previous question, can a tool be developed to demonstrate the impact of the specified variables on expected channel delays and develop time-based cancellation decision points for TACC planning and execution cells?

In an attempt to answer both parts of this question with one device, the researcher developed an Excel-based tool. This includes a user-friendly interface with drop-down options for MDS, aircraft home station and aircrew wing. Airport of departure, destination and current delay must be manually entered. Based on the inputs, the model mines this study's data set to present a graphical depiction of the cumulative distribution function (CDF) and probability distribution function (PDF) of both crew/maintenance delays and other delays. The expected delay on each graph is at the intersection of these PDF and CDF lines, and the current delay is shown as a vertical green line. The exact expected delay, based on the median of delay severities associated with the variable selections, is also shown in a separate data window. Finally, as a demonstration of the viability of the output, the number of data points used to present the results is shown with a warning to use data with caution if there are less than 30 data inputs.

IV. Results and Analysis

The functionality of Excel 2007 was used throughout the completion of this study. Prior to analyzing the data set with respect to specific variables, a basic analysis of C-5 channel missions provided categorical evidence of the breakdown of new (non-carry-over, or X) delays. Some in AMC leadership have criticized the capability of the C-5, claiming that the DR is less than 20%, but this may be due to reporting and mission management practices instead of aircraft capability. Table 4 below shows that better than 50% of C-5 channel sorties took off on time with respect to landing time, and only 18.5% of scheduled takeoffs experienced new delays due to aircraft maintenance. Those delay categories marked with an asterisk are those that were considered "crew or maintenance delays" for the purposes of this study.

Table 4. C-5 Channel Delay Distribution

Delay Category	Percent of Channel Departures
On Time	50.47
Maintenance*	18.50
Departure/Arrival Airfield Closure	8.48
Other Miscellaneous	7.53
Preventable Crew Delays*	4.19
Weather	2.29
Services, Customs, Etc.	1.80
Crew Rest/Crew Duty Day	1.30
Unit Overcommitted	1.30
Supply	1.10
Air Traffic Control	1.05
Other Crew Delays	1.05
Crew Enhancement	0.95

Question 1: Analysis of Historical Data

A table of consolidated results is included in Appendix A. To highlight the importance of each individual variable (aircraft type, aircraft home station, aircrew service component, departure location, and combat status), a short analysis of key results follows. Results may conflict with expectations and historical perceptions of the C-5, and consideration should be given to the fact that findings are based on only a one-year data set. For all figures, average and expected (median) delay is plotted against the left vertical axis while probability of delay is plotted against the right vertical axis.

Aircraft Type

Data was first analyzed for propagation (occurrence) and severity of delays for each aircraft type. Surprisingly, the worst performer was the C-5B, with 23.79% of sorties experiencing a new crew or maintenance delay, and an average delay time of 59.37 hours. For expected delay, however, the C-5A was slightly worse than the B-model, with an expected delay of 24.83 hours. The figure below shows delay results with respect to aircraft type.

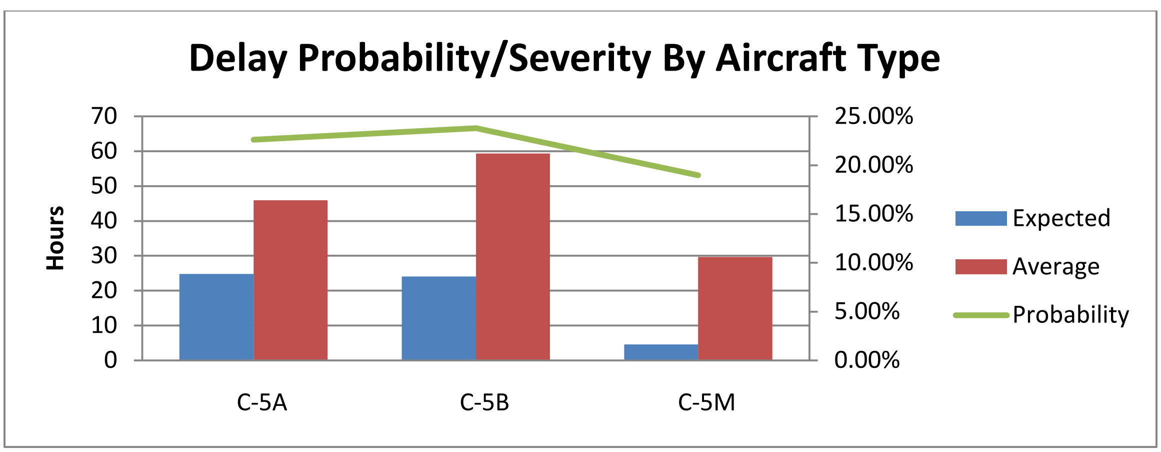


Figure 3. Aircraft Type Analysis Results

Aircraft Home Station

The home station of the aircraft could impact delay propagation and severity in two ways. First, the training and mission-moving mindset of the crew force flying their aircraft could impact the decision process of individual crew members considering a delay. Also, the maintenance of C-5 aircraft is not perfectly standardized across the force. The analysis of the data showed that aircraft from Wright-Patterson Air Force Base (AFB) were the most likely to delay, with more than 33% of their sorties experiencing a new crew or maintenance delay. Aircraft from Martinsburg had the highest average delay (69.97 hours), but with a delay probability of less than 18%. Westover aircraft had the worst expected delay at 39.33 hours. Stewart aircraft performed best overall, flying 14.06% of the departures, but with only 8.13% of the new delays and 6.78% of the total delay time (see Appendix A). The results for all locations with C-5 aircraft assigned are below.

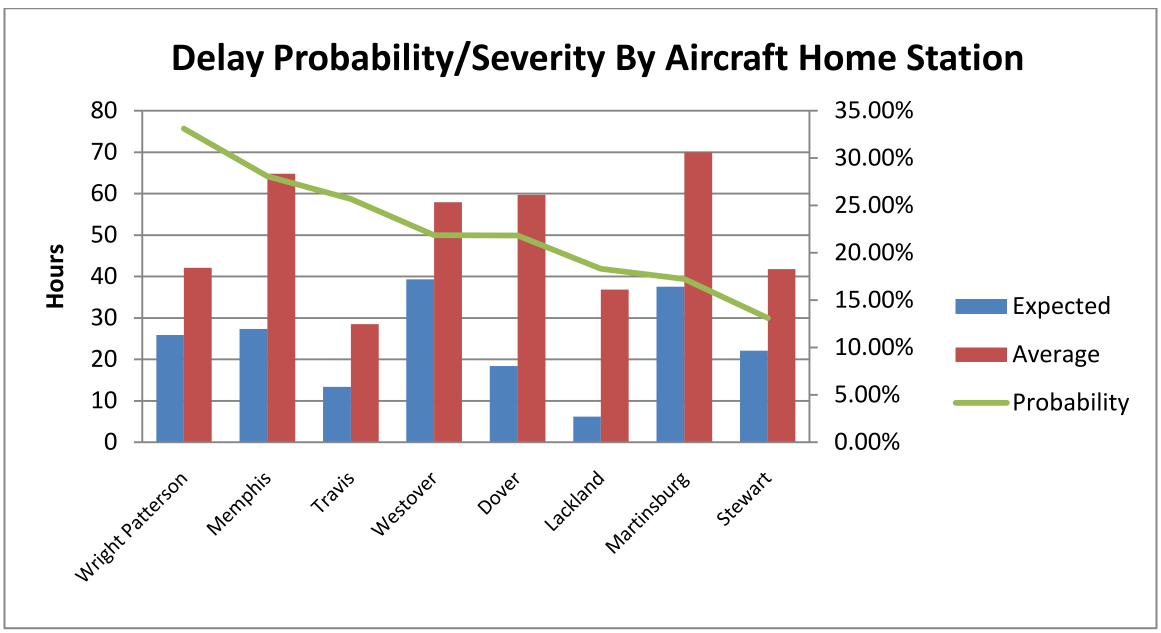


Figure 4. Aircraft Home Station Analysis Results

Aircrew Service Component

As previously mentioned, some believe that Guard and Reserve crews are more likely to have severe delays as compared to Active Duty crews. The researcher attempted to disprove this line of thought based on an analysis of the data set. The results showed that the probability of a new crew or maintenance delay occuring was virtually the same at just under 23%. Also, the average delay was slightly higher for Guard/Reserve crews. Unexpectedly, the median delay for Guard/Reserve crews was significantly higher…more than 17 hours greater than the expected Active Duty delays. The figure below shows these results.

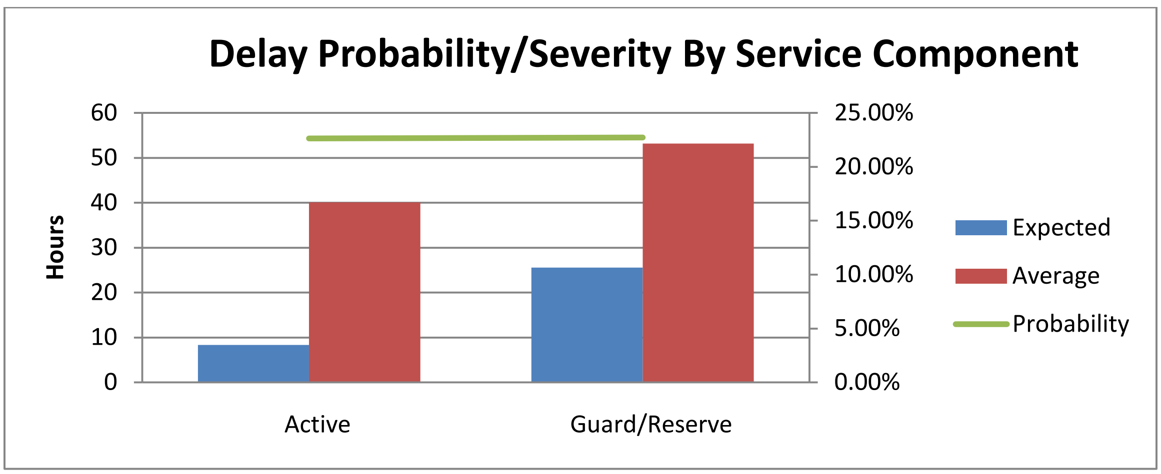


Figure 5. Service Component Analysis Results

Departure Location

More than any other variable, departure location can significantly impact the probability and severity of delays. When considering crew and maintenance delays, some have inferred that crews choose to 'break' at desirable locations. Also, repairs on malfunctioning aircraft are completed more quickly at those locations that are equipped for C-5 maintenance. Obviously, other location-specific factors impact the probability and severity of delays not specifically attributed to the crew or maintenance. The analysis of the crew and/or maintenance delay data showed that aircraft departing Wright-Patterson AFB (KFFO) are most likely to have problems, with 66.67% of the 48 departures in the data set experiencing a new crew or maintenance delay. Kuwait International (OKBK) had the worst average delay at 111.83 hours, and its expected delay was 79.15 hours (based on 13 data points). However, Spangdalhem Air Base (ETAD) was identified as the location with the worst severity, with an expected delay of 80.05 hours (based on 21 delays). Bagram Airfield in Afghanistan had the lowest propagation of delays, with just 3.77% of the 53 departures having a new crew or maintenance delay. Stewart International, a C-5 home station, had the shortest delay severity, at 1.68 hours (based on 10 data points). The figure below shows the location-specific results. There will be no delay data for those locations with less than 10 delays. The 'Other' position at the far right of the X-axis shows the probability for those locations with less than 10 departures and the overall expected/average severity for those locations with less than 10 delays.

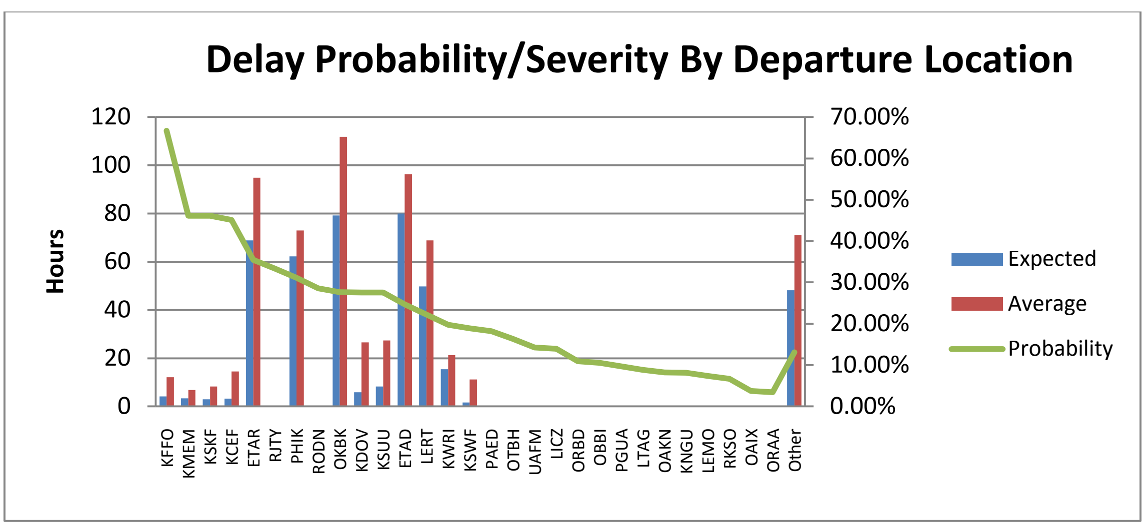


Figure 6. Departure Location Analysis Results

Combat Status

Aircraft technical orders and minimum equipment lists attempt to standardize the decision making processes when maintenance issues occur. However, aircrews have been known to go ‘above and beyond’ in their efforts to minimize the impact on combat or combat support sorties. If an aircraft systems problem does occur downrange, then more severe delays are likely due to limited maintenance repair capability. The analysis of the data with respect to sortie combat status supported this perception. Surprisingly, delays that occurred for sorties between downrange locations were more severe than those for sorties departing a downrange location for a non-combat location. Only 5.88% of the 187 sorties between these downrange airfields experienced a delay, but the median (expected) delay was 80.25 hours. Sorties that are not associated with downrange locations have the highest probability of delay (26.01%), but have an expected delay of only 17.47 hours.

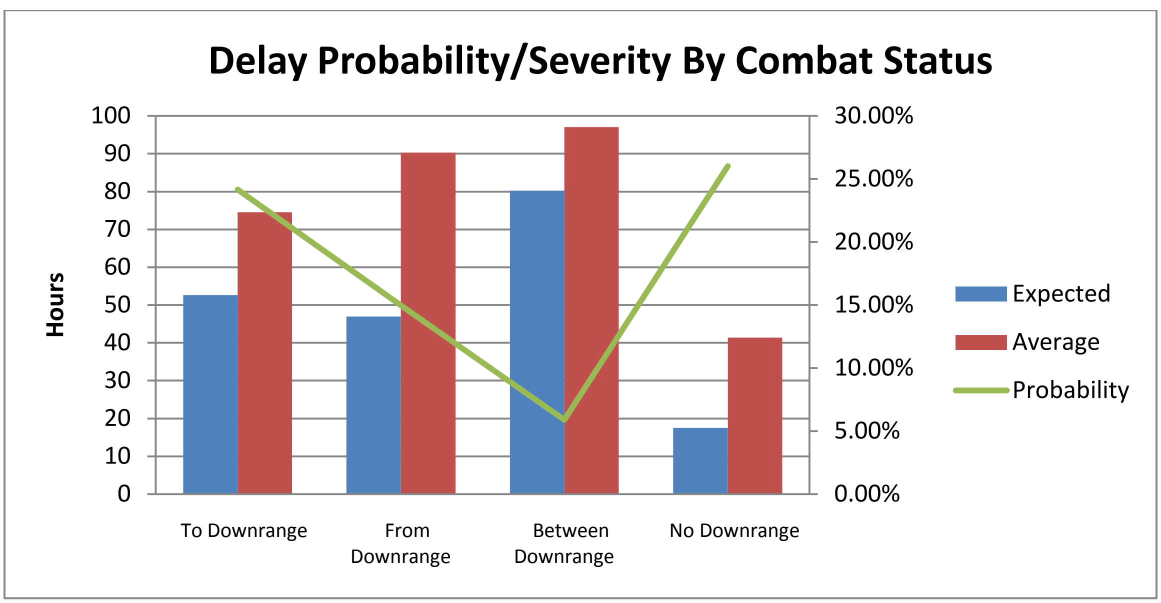


Figure 7. Sortie Combat Status Analysis Results

Delays Not Caused By Crew or Maintenance

The focus of this study is on those C-5 channel delays caused by crew issues or maintenance. However, other location-specific factors such as transportation, weather, and supply can significantly impact the propagation and severity of delays in the channel system. An examination of all delays attributed to each specific cause is beyond the scope of this study, but an overall analysis is presented below. All delays beyond those previously considered are included and are considered with respect to departure location only. C-5 aircraft departing Spangdalhem Air Base, Germany, have the highest probability of a delay with 52.94% of the 85 departures experiencing a delay during the data period. Spangdalhem also had the worst severity, with a median delay time of 68.33 hours. Wright-Patterson AFB has the shortest expected delay at 1.35 hours (based on 11delays over 48 scheduled departures).

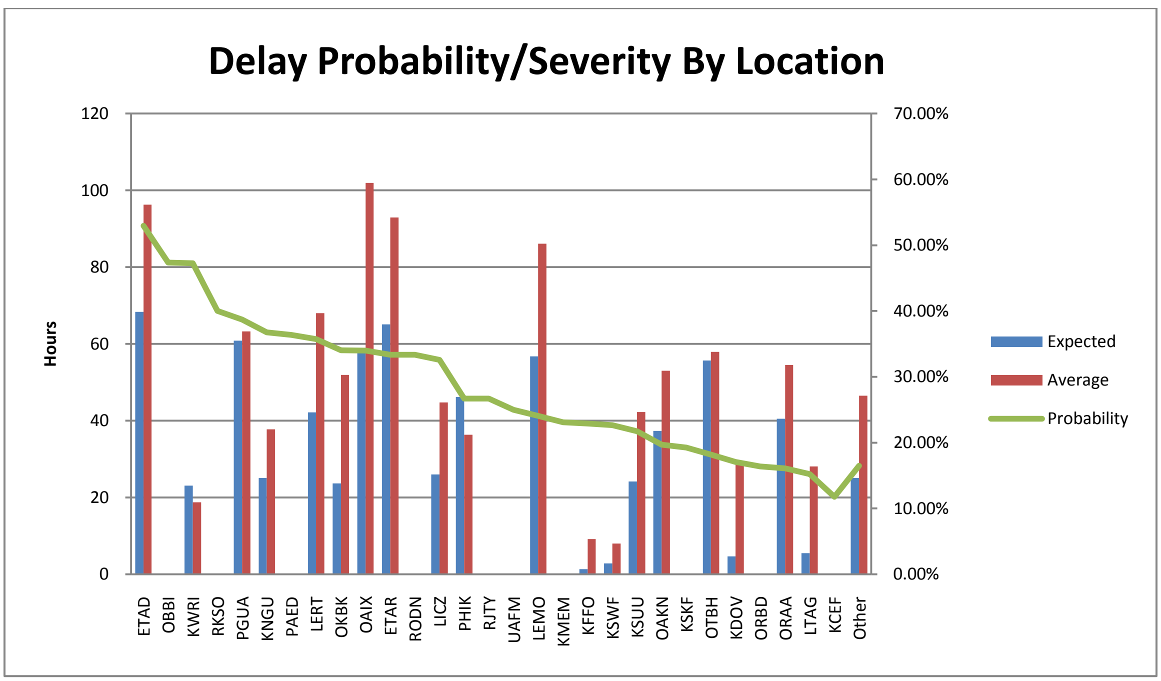


Figure 8. Delays Not Attributed To Crew or Maintenance Analysis Results

Question 2: Time-based Decision Tool

While many factors influence the possibility and severity of delays, this analysis of historical data can be used to develop a tool that could provide an 'expected delay' when given values for aircraft type, aircraft home station, aircrew service component, departure location, and combat status. Such a tool could be used during the decision making process when considering cancellation or rescue of a delayed C-5 channel mission. As discuessed in Chapter 1, caution should be used when implementing this or any other time-based tool. Other factors such as cargo importance, dimplomatic clearances, crew sortie return time and cargo required delivery date could be more important to cancellation decisions than any simple time-based calculation. However, a tool that predicts an expected delay severity could be a valuable resource in providing a 'starting point' during the channel delay management decision process.

Appendix B shows an example of the user interface and results provided by the instrument developed in this study. Instead of focusing on each variable individually, the impact of all variables are combined with an equal bias. Drop-down choices are available for users to enter aircraft type (MDS), aircraft wing and aircrew wing. A four-digit airport identifier code must be manually entered in the delay location and planned destination fields. Additionally, the user may choose to manually enter the length of the current delay in hours. The data mining capability of Microsoft Excel is used to determine the frequency and severity of channel delays on missions during the data period that had similar variable values. The frequency function of Excel is then used to determine the number of delays associated with each .5 hour severity bin. For example, if an active duty aircrew is delayed on a C-5A, all C-5A delays and all active duty delays are considered. By design, delays could be counted as many as five times (one for each variable). This provides for equal possibility of impact for each variable.

The output of this tool is presented in several ways. Easiest to interpret is the “Expected Crew/Mx Delay” field. This result is the median of all delay severity values associated with each of the variables entered by the user. Most visible is the graphical depiction of the probability distribution and cumulative distribution functions of the delay severities associated with the user inputs. The intersection of these lines occurs at the point on the graph corresponding with the “Expected” delay value. If the user chooses to input the current delay time, a vertical green line will show the current delay with respect to the delay distribution. The figure below is the graphical output for an active duty crew on a Travis AFB C-5B that is 10 hours in delay on a Ramstein Air Base to Djibouti flight.

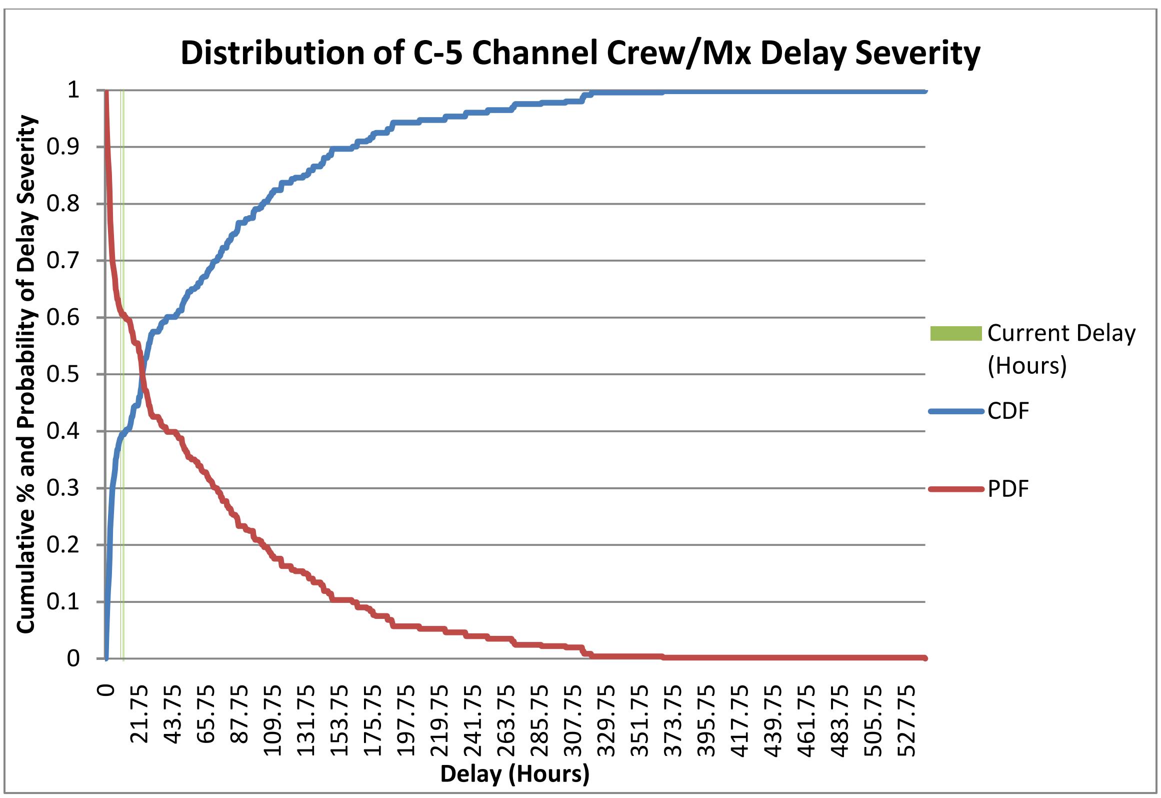


Figure 9. Expected C-5 Channel Crew/Mx Delay Graphical Output

In addition to these primary (desired) results, several additional outputs are provided. A similar analysis of delays not caused by the crew or maintenance is completed to produce similar outputs (Expected Delay and graphical depiction of the PDF and CDF). These delays are attributed only to the delay location regardless of the individual delay codes, so the number of data points considered are significantly less. To address the possibility of results based on limited data, the number of data points used to determine the results is displayed for both crew/maintenance and other delay outputs. Finally, a table showing the level of impact of each of the variables considered allows users to examine the relative influence of changes in each variable. Table 5 below shows these results for the example mission described to produce Figure 8 while Table 6 is the output if the crew type was changed to Guard or Reserve (no other changes). This increase in the level of impact is expected due to the higher percentage of channel missions flown by Guard and Reserve aircrews, demonstrating that it may be difficult to generalize results to a category of variables without consideration of the inputs.

Table 5. Impact of Each Variable on Expected Crew/Mx Delay

Level of Variable Impact (1 for most, 5 for least)		Impact
MDS	1	42.07%
Crew Component	2	23.57%
Aircraft Home Station	5	10.35%
Combat Status	3	13.00%
Location	4	11.01%

Table 6: Variable Impact After Changing Crew Type

Level of Variable Impact (1 for most, 5 for least)		Impact
MDS	2	27.48%
Crew Component	1	50.07%
Aircraft Home Station	5	6.76%
Combat Status	3	8.49%
Location	4	7.19%

In attempt to verify the validity of this tool, an analysis of data for the period of 1 August to 31 December 2010 was completed and prediction results were compared against those from the orginal data period (1 August 2009 to 31 Jul 2010). Using multiple 'sample' missions, the difference in the median/expected delay and the average forecast error (mean absolute deviation) were calculated. Unfortunately, there were significant differences in the expected delay, although the average error was less than 5% in most cases. The table below shows some of these results.

Table 7. Test of Validity

Inputs					Forecast Error	
MDS	Component	Home Station	Combat Status*	Delay Location	Expected Delay Error** (hours)	Average Error (MAD)
C-5A	Active	KDOV	To	LERT	-14.57	3.56%
C-5A	Active	KSUU	Non-Combat	PHIK	-9.8	3.66%
C-5A	Reserve	KDOV	From	OBBI	-6.15	3.18%
C-5A	Reserve	KSUU	Non-Combat	KDOV	-6.18	3.09%
C-5B	Active	KDOV	Between	ORAA	-25.05	4.61%
C-5B	Active	KSUU	Non-Combat	KSUU	-18.05	3.89%
C-5B	Reserve	KSKF	To	ETAR	-15.18	3.05%
C-5B	Reserve	KMRB	Non-Combat	KDOV	-7.41	3.07%
C-5B	Reserve	KMEM	From	UAFM	-11.78	3.16%
C-5B	Reserve	KSWF	Non-Combat	LEMO	-6.15	2.87%
C-5B	Reserve	KCEF	Between	OAIX	-9.58	2.79%
C-5B	Reserve	KFFO	Non-Combat	ETAD	-10.9	3.69%
C-5M	Active	KDOV	To	LICZ	-25.73	5.40%
C-5M	Active	KDOV	Non-Combat	KWRI	-34.03	5.97%
* - "To", "From", or "Between" CENTCOM AOR Locations						
** - Negative Error indicates forecast was less than actual						

The results of this test demonstrate that for the most recent data considered, this tool provided expected delays that were less than the actual delay in most cases, and significantly less than actual in some cases. After examining the data, it became apparent that the distribution of delay severities during the August through December 2010 period differed considerably from the data period considered in this study. The figure below shows the cumulative distribution of the delay severity of each data set.

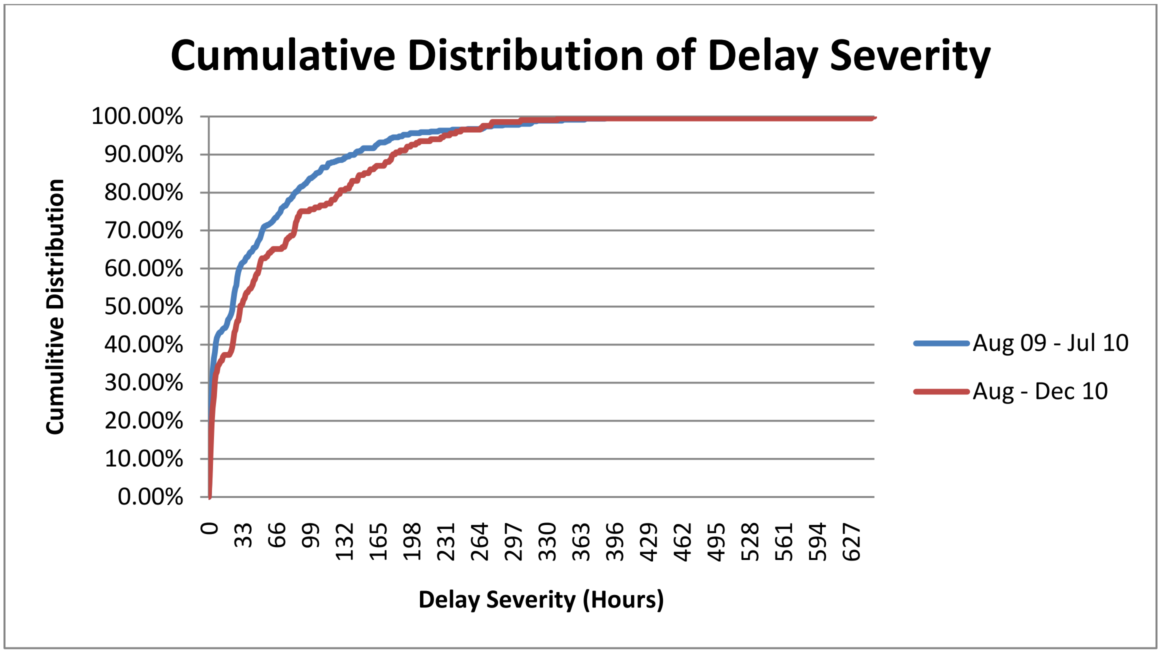


Figure 10. Cumulative Distribution of Delay Severity

The cumulative delay severity difference between the data sets indicated the need for an additional assumption. If the tool developed in this study is to be considered suitable for use in predicting the severity of individual delays, then the applicable channel mission schedule and delay propagation/severity must mirror the research data set. However, even if there are significant differences, the results of this instrument could be used as a starting point when mission managers are considering all available options. As a measure of current validity, allowances were built in to test the tool against a current data set. A separate tab on the Excel product indicates the error level at the expected delay severity (normally the maximum error) and the average error (mean absolute).

V. Conclusion and Recommendations

Conclusion

The literature review conducted during this research effort identified several points for consideration when addressing C-5 delays. First, maintenance organizations are lacking in the manpower and experience levels needed to properly complete their mission of generating capable aircraft. Also, the metrics used to track aircraft performance vary by organizational level, preventing maintenance personnel from working towards a goal that directly contributes to mission effectiveness. Finally, the process used by mission managers to track departure reliability is flawed, counting many delays multiple times instead of just the initial occurrence.

An analysis of any data set over a different discrete periods can produce conflicting results. However, this study focused on specific variables over a one-year period in an attempt to account for seasonality and random significant events. While variables other than those considered may have significant impact on the propagation and severity of C-5 channel delays, this study calls attention to the results associated with each of the specified variables.

It is fairly simple to draw conclusions about the propagation of delays throughout a given C-5 channel mission set. The analysis of delay severity, however, shows that the data set is characterized by a fair number of outliers. This is identified by the large gap between the expected (median) severity associated with each variable as compared to the average (mean) delay. Severity results tied to the C-5M, for example, show that the expected delay was 4.58 hours, but the average was 29.65 hours. This is in contrast with Guam Air Base, where 38.71% of departures experienced a new crew or maintenance delay, with an expected severity of 60.85 hours and an average of 63.24 hours. A plot of the delay severities at Guam would more closely resemble a normal distribution, while the plot of the severity associated with most other variable values would be skewed to the right, resembling a Chi Square distribution (with 4 degrees of freedom or less).

It should be noted that interpretation of the analysis results can influence the perceived importance of different variables and their values. For example, Kuwait International and Spangdalhem Air Base were identified as the locations with the worst performance for delay possibility and severity, respectively. However, Appendix A shows that Ramstein Air Base (ETAR) had 7% of the total C-5 channel departures, but produced 11% of the total delays with 20.8% of the overall delay time. When attempting to use the results of this study to draw generalizations, all data should be considered to avoid misinterpreting the results.

The expected delay mission management tool developed in this study can be very useful as a starting point in decision making when a delay occurs. It also could be modified to display probability and expected severity of delays for use during mission planning. The shape of the PDF/CDF plot can be very indicative of the level of confidence that should be used when using this instrument. For example, a plot that is spread over a large data range with a gentle slope of the curves would have a lower level of confidence.

System Recommendations

While this study focused specifically on the performance of the C-5 channel system, the researcher has no specific recommendations that are limited to that system. However, several overal C-5 system recommendations are appropriate.

First and foremost, maintenance organization should be properly manned, both in the number of personnel assigned and the experience level of the workforce. The *C-5 TNMCM Study II* clearly demonstrated the lack of proper manning in Air Force maintenance units. Although military budgets are currently being threatened and overall force manning is being reduced, the flying mission must be supported properly if Air Force objectives are to be accomplished.

Additionally, AMC leadership should develop and track metrics that are directly tied to mission effectiveness instead of capability. There are indications that departure reliability, both home station and world-wide, measure effectiveness better than mission capability. Even more effective would be a metric that measures delivery reliability based on the Required Delivery Date instead of just aircraft or unit-level departure reliability. Either way, the standard for MC rates should be 100%, but MC tracking should not occur. Also, maintenance personnel should be required to schedule all required maintenance actions instead of performing some repairs or inspections when the aircraft is not on a scheduled flight. This would allow maintainers to complete required work without the threat of punishment while providing visibility of actual aircraft availability to OG and higher leadership.

Each time a delay occurs during a mission, that mission should be recut to show a new estimated time of departure for each of the following mission sorties. The initial analysis of the data set used to initiate this study (January-March 2010) led some to believe that DR was only 18%. However, later analysis using only new delays showed that DR for the research data set was actually 50.47%. If only crew and maintenance issues are considered, 77.31% of C-5 channel departures were capable of departing as scheduled. While the workload for mission managers may increase slightly with this proposed change in their processes, it could improve visibility of new delays and ease planning and coordination efforts for future legs that are impacted.

Finally, the leadership of all C-5 maintenance and operations organizations (both home station and enroute locations) should be encouraged to review the results of this study and seek out areas for home station and system-wide improvement. For example, Wright-Patterson AFB and Stewart ANGB aircraft flew approximately the same number of channel missions, but Wright-Patterson aircraft experienced far more delays and higher severities. If differing crew and/or maintenance procedures can be identified, then Wright-Patterson and Stewart leaders could work to develop best practices that could be implemented and recommended for all other C-5 wings.

Recommendations for Future Research

While the data period selected for this study was designed to account for variability due to multiple factors, an expansion of the data set could be used to improve the confidence level of analysis results and severity predictions. Initially, a five-year data period could be utilized. However, consideration should be given to the characteristics of the current mission schedule and performance as compared to the data set used. As discussed in the previous chapter, if the mission schedule and delay characteristics do not match the data set, then results and predictions could be unreliable.

An additional area for future research could be an examination of the relationship between each variable and the actual impact on predicted severity. Currently, no bias is given to each variable to reduce the impact of those variables with the least number of options. Aircraft type and aircrew component will normally have the highest impact on expected delay due to the number of data points considered by the design of the prediction tool. Additionally, missions on aircraft originating from Guard or Reserve locations will, by default, be manned by Guard or Reserve aircrews. The tool developed in this study builds delay predictions with a greater weight from the aircrew component than from the aircraft home station (due to the large number of component data points). If a bias factor could be devloped that accounts for the relationship between variables, then the accuracy of this instrument could improve greatly.

Finally, an independent study of aircrew and maintenance practices should be accomplished to determine differing procedures and techniques that directly contribute to mission effectivenes. To be most effective, crews and maintainers should be directly observed, but a study of that magnitude could be time and cost prohibitive. However, a survey-based study could also provide results that could be extremely useful. Importantly, a consideration of differing practices used by C-5M aircrews could be beneficial. While there have been claims of greatly improved reliability due to aircraft modifications, some crew members have indicated that an increased focus on mission completion has also contributed to the C-5M's success.

Final Thoughts

This paper's intent was to examine several variables that could be causal factors with respect to delays in the C-5 channel system. While there is no generalizable evidence of specific correlation or causality between variables and results, it was clear that the possibility and severity of delays varied with changes in the variables considered. The first part of this study focused on the historical development and performance of the C-5 and identified some of the challenges facing the maintenance force and mission managers. The study showed that, based on the analysis of data from a one-year period, delay propagation and severity varies significantly based on changes in C-5 model type, aircraft home station, departure location, and sortie combat status. The researcher hypothesized that differences in crew component would not have significant impact on delays. However, while the possiblity of a channel delay did not change with crew component, the expected severity was significantly lower for active duty aircrews. This study also developed an instrument that can be used to predict the severity of delays that occur in the channel system. While the efficacy of the tool may be limited to use during those mission sets that mirror those flown during the research data period, the prediction can aid mission managers and decision makers when channel delays occur.

To improve channel system and overall C-5 aircraft performance, AMC leadership must be willing to make difficult decisions. While some may believe that maintenance manning shortfalls do not directly impact performance, the number and proficiency level of personnel assigned to maintenance organizations is far below what is needed to maintain the desired level of effectiveness. Metrics should focus on mission performance instead of mission capability, and maintainers should be given the freedom to keep aircraft at the highest levels of readiness without penalties for the loss on capability during maintenance actions. When delays do occur during a mission, future sorties of that mission should be rescheduled to improve the accuracy of mission planning efforts and performance tracking. If maintenance and operations leaders can implement these changes and standardize processes, there could be dramatic improvements in C-5 and channel system reliability and improved confidence in sustainment deliveries to the warfighter.

Appendix A: Analysis Results

A - Percent of Total Channel Departures
B - Percent of Total New Delays
C - New Delay Probability
D - Percent of Total Delay Time
E - Total Delay Time (Hours)
F - Average Delay Time (Hours)
G - Expected Delay Time (Hours)

	Probability Results			Severity Results			
	A	B	C	D	E	F	G
Aircraft Type							
C-5A	49.18%	49.01%	22.62%	44.92%	10241.18	45.92	24.83
C-5B	40.05%	41.98%	23.79%	49.74%	11340.05	59.37	24.07
C-5M	10.77%	9.01%	18.98%	5.33%	1215.55	29.65	4.58
Aircraft Home Station							
Dover	26.73%	25.71%	21.83%	30.65%	6986.27	59.71	18.35
Lackland	8.98%	7.25%	18.33%	5.33%	1214.88	36.81	6.17
Martinsburg	2.89%	2.20%	17.24%	3.07%	699.72	69.97	37.51
Memphis	8.53%	10.55%	28.07%	13.64%	3109.92	64.79	27.35
Stewart	14.06%	8.13%	13.12%	6.78%	1544.60	41.75	22.10
Travis	9.13%	10.33%	25.68%	5.87%	1338.40	28.48	13.38
Westover	15.06%	14.51%	21.85%	16.76%	3820.52	57.89	39.33
Wright-Patt	14.61%	21.32%	33.11%	17.91%	4082.48	42.09	25.88
Aircrew Service Component							
Active	23.59%	23.52%	22.62%	19.00%	4330.73	40.10	8.35
Guard/Reserve	76.41%	76.48%	22.72%	81.00%	18466.05	53.22	25.53
Departure Location							
ETAD	4.24%	4.62%	24.71%	8.87%	2021.97	96.28	80.05
ETAR	7.03%	10.99%	35.46%	20.80%	4741.08	94.82	68.83
KCEF	2.54%	5.05%	45.10%	1.46%	332.08	14.44	3.17
KDOV	19.00%	23.08%	27.56%	12.21%	2784.48	26.52	5.92
KFFO	2.39%	7.03%	66.67%	1.70%	386.43	12.08	4.18
KMEM	1.30%	2.64%	46.15%	0.36%	82.32	6.86	3.36
KNGU	2.44%	0.88%	8.16%	0.63%	144.20	***	***
KSKF	1.30%	2.64%	46.15%	0.43%	98.97	8.25	2.94
KSUU	3.44%	4.18%	27.54%	2.29%	521.15	27.43	8.28
KSWF	2.64%	2.20%	18.87%	0.49%	112.38	11.24	1.68

KWRI	4.54%	3.96%	19.78%	1.68%	382.05	21.22	15.38
LEMO	2.69%	0.88%	7.41%	0.61%	139.02	***	***
LERT	10.32%	10.11%	22.22%	13.90%	3167.75	68.86	49.74
LICZ	2.14%	1.32%	13.95%	2.02%	460.77	***	***
LTAG	3.94%	1.54%	8.86%	0.99%	226.42	***	***
OAIX	2.64%	0.44%	3.77%	0.51%	116.90	***	***
OAKN	3.04%	1.10%	8.20%	1.24%	282.25	***	***
OBBI	0.95%	0.44%	10.53%	0.52%	117.85	***	***
OKBK	2.34%	2.86%	27.66%	6.38%	1453.85	111.83	79.15
ORAA	4.34%	0.66%	3.45%	1.25%	284.22	***	***
ORBD	2.74%	1.32%	10.91%	1.20%	274.50	***	***
OTBH	2.74%	1.98%	16.36%	2.41%	549.65	***	***
PAED	0.55%	0.44%	18.18%	0.41%	92.82	***	***
PGUA	1.55%	0.66%	9.68%	1.59%	361.55	***	***
PHIK	2.24%	3.08%	31.11%	4.48%	1022.25	73.02	62.27
RJTY	0.75%	1.10%	33.33%	1.79%	407.88	***	***
RKSO	0.75%	0.22%	6.67%	0.72%	164.42	***	***
RODN	1.05%	1.32%	28.57%	1.60%	365.27	***	***
UAFM	1.40%	0.88%	14.29%	4.21%	959.43	***	***
Other	2.94%	2.42%	13.08%	3.26%	742.88	71.13	48.21
Other for Probability is average for all locations with less than 10 departures							
Other for Severity is mean/median for all locations with less than 10 delays							
*** - Those locations with less than 10 delays							
Combat Status							
To Combat	10.52%	11.21%	24.17%	16.68%	3801.37	74.54	52.65
From Combat	11.32%	7.47%	14.98%	13.46%	3068.72	90.26	46.98
Between Combat	9.33%	2.42%	5.88%	4.68%	1067.57	97.05	80.25
No Combat	68.83%	78.90%	26.01%	65.18%	14859.13	41.39	17.47

Appendix B: Expected C-5 Channel Delay Instrument User Interface and Results

C-5 Channel Delay Severity With Respect To MDS, Crew Component, Aircraft Home Station, Combat Status and Delay Location

User Inputs:

Instructions:
- Choose from dropdown for MDS, Aircraft Wing, and Aircrew Wing
- Manually enter Delay Location, Planned Destination, and Current Delay
- Crew/Mx and Other Delay Severity Charts will adjust automatically
- Reference appropriate chart based on delay type (crew/mx or any other)
- Caution should be used when using results based on less than 30 data points

If Current Delay exceeds Expected Delay, Consideration SHOULD BE given to cancelling the mission

MDS:	C5B
Aircraft Wing:	167AW
Aircrew Wing:	167AW
Delay Location (ICAO):	pgua
Planned Destination (ICAO):	rjty
Current Delay (Hours)	10

Level of Variable Impact (1 for most, 5 for least)		Impact
MDS	2	34.60%
Crew Component	1	63.04%
Aircraft Home Station	3	1.81%
Combat Status	5	0.00%
Location	4	0.54%

Chart below based on the following number of data points: 552
Expected Crew/Mx Delay: 24.85 Hours

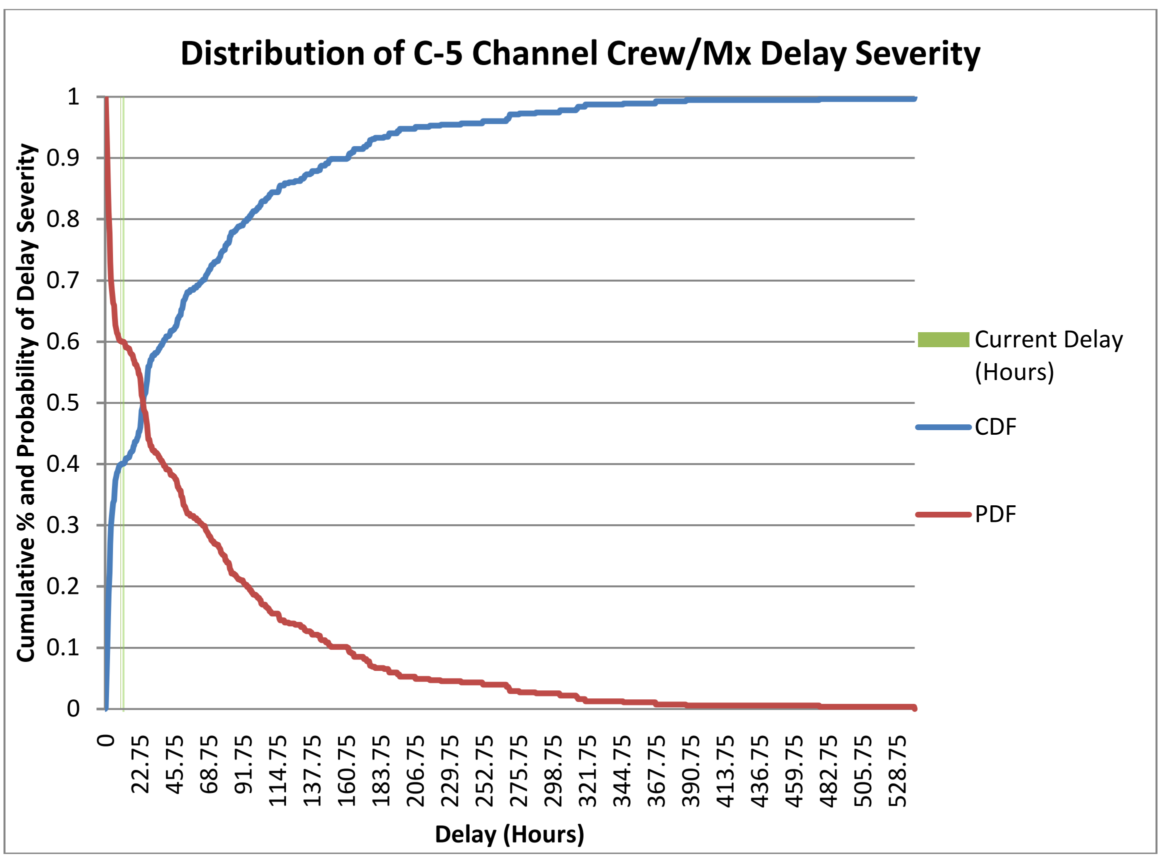
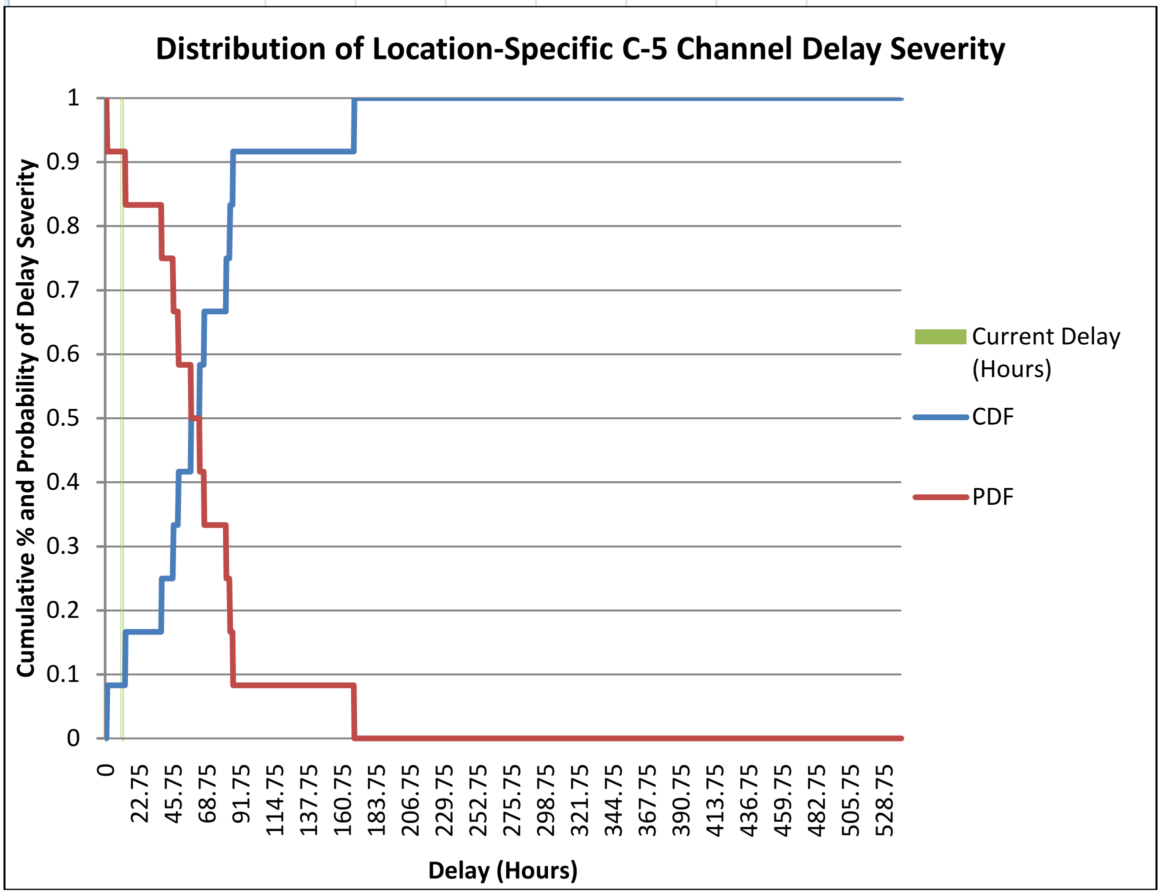


Chart below based on the following number of data points:	12	
Expected Delay (not related to crew/mx):	60.85	Hours



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Blue Dart

The Air Mobility Command channel system is an essential part of the Department of Defense supply chain network. While the C-5 Galaxy is a key contributor to channel mission success, mission delays have plagued operations and reduced the effectiveness and efficiency of deliveries to the warfighter. Inappropriate manning levels and performance measurement techniques have hampered maintenance efforts at home-station and enroute locations. Additionally, current mission management practices increase the perception of unreliability in the C-5. However, even when considering only new and unique situations, there are an inordinate number of crew and maintenance delays that are characterized by an excessive severity.

Air Force leaders rely on Departure Reliability (DR) and Mission Capability (MC) rates to measure C-5 performance, and DR for C-5 channel missions is far below the desired level. DR can be affected by weather, diplomatic clearances, or other factors, but there is a perception that equipment failures drive most mission delays. In the first quarter of 2010, 81% of C-5 channel departures operated in some sort of delay, but only 31% of those delays were due to maintenance. MC rates measure the percentage of aircraft functioning at levels that allow mission completion. Low MC rates are common, with 2005-2007 data showing C-5 MC rates of only 48% for C-5A/C and 65% for C-5B. Potential causal factors for the C-5's unacceptable performance have never been thoroughly investigated or defined beyond a broad 'poor maintenance' label. More importantly, AMC leadership has grown so accustomed to maintenance delays on C-5 channel missions that they are an expected occurrence.

An analysis of C-5 channel performance over a one-year period showed significant changes in delay propagation and severity with respect to aircraft type, aircraft home station, aircrew service component, departure location, and combat status. These variables are not independent, but were treated as such for the purposes of this study.

The C-5M performed much better than the A or B-model, with a 19% chance of a new delay and an expected severity of 4.58 hours. Aircraft from Wright-Patterson AFB had the greatest delay potential, with over 33% of departures experiencing a new crew or maintenance delay, while Westover aircraft had the worst expected delay at 39.33 hours. When considering service component, the researcher had hypothesized that there would be no significant difference in delay results. However, while the probability of a new crew or maintenance delay occuring was virtually the same at just under 23%, the median delay for Guard/Reserve crews was more than 17 hours greater than expected Active Duty delays.

Results based on delay location were also wide-ranging, but Wright-Patterson AFB had the greatest potential for new delays, at 66.67%. Spangdalhem Air Base (ETAD) was identified as the location with the worst severity, with an expected delay of 80.05 hours, and Stewart International, a C-5 home station, had the shortest delay severity, at 1.68 hours. Combat status speaks to crew motivation when considering the use sub-standard equipment with a heightened threat, and delay results were as expected. Only 5% of sorties between combat-zone airfields experienced a new delay. Delay severity for these mission segments was highest, at 80.25 hours, due to a possible shortage of personnel and equipment at these locations.

The researcher developed an Excel-based instrument that predicts expected delay severity based on the historical data considered in this study. This provides a good starting point when deciding whether a C-5 channel mission should be cancelled, but the limitations of any prediction must be considered. Many other variables may have significant impact on the propagation and severity of C-5 channel delays. Additionally, serious consideration should be given to other mission-specific factors such as maintenance availability, crew scheduled return time, diplomatic clearances, alternate aircraft availability, cost optimization and cargo prioritization.

To improve channel system and overall C-5 aircraft performance, AMC leadership must be willing to make difficult decisions. The number and proficiency level of personnel assigned to maintenance organizations is far below what is needed to maintain the desired level of effectiveness. Also, metrics should focus on mission performance instead of mission capability, and maintainers should be given the freedom to keep aircraft at the highest levels of readiness without penalties for a loss of capability during maintenance actions. When delays occur during a mission, rescheduling of future sorties of that mission could improve the accuracy of mission planning efforts and performance tracking. If maintenance and operations leaders can implement these changes and standardize processes, there could be dramatic improvements in channel system reliability and improved confidence in C-5 sustainment deliveries to the warfighter.

Storyboard / Quad Chart

C-5 Channel Delays: Analysis of Potential Causal Factors

Maj Matthew T. Vann
Advisor: James T. Moore, Ph.D.
Sponsor: Donald R. Anderson
Advanced Study of Air Mobility (ASAM)
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Introduction

The C-5 Galaxy is a key contributor to channel mission success, but delays have plagued operations and reduced the effectiveness and efficiency of deliveries to the warfighter.

This research attempted to establish a correlation between the propagation and severity of C-5 mission delays in the channel system and the following variables: aircraft type, aircraft home station, aircrew service component, departure location, and combat status. The results of this analysis were used to develop an Excel-based instrument that provides a predicted severity for a given C-5 delay.

Research Goals

- Explore and demonstrate the relative impact of certain factors on the possibility and severity of C-5 channel delays
- Develop a tool that can use historical data to predict delay severity when given a specified set of mission-specific variables.

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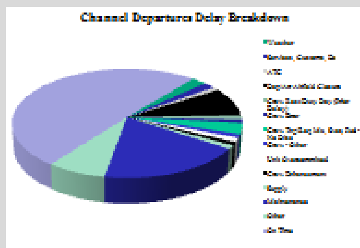
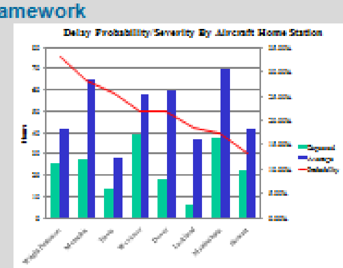
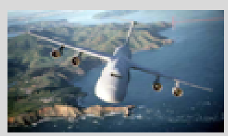
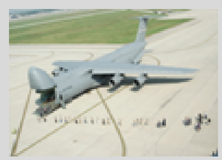
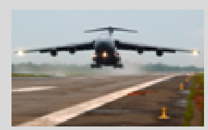
General Framework

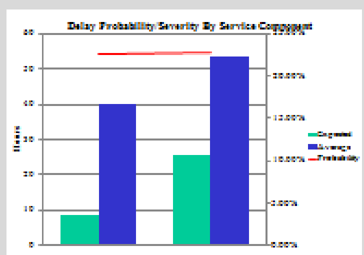






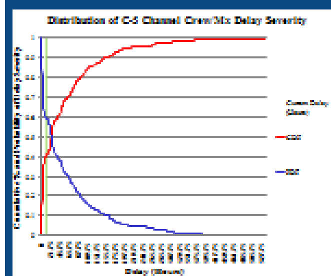






Level of Variable Impact (1 for most, 5 for least)		Impact
MDS	1	42.07%
Crew Component	2	25.57%
Aircraft Home Station	5	10.35%
Combat Status	5	15.00%
Location	4	11.01%

Application – Delay Prediction



Motivation

- Warfighter depends on timely and reliable delivery of channel cargo.
- Lack of leadership focus on C-5 and channel system capability.

Impacts/Contributions

- Increased capability for informed decision making when C-5 channel delays occur.
- Identified need for improved home station and enroute location performance.

Collaboration

Air Mobility Command A9/AA9
618th TACC Global Channel Operations

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